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**Low-Cost
Solar Array Project**

DOE/JPL-1012-30
Distribution Category UC-63b

(NASA-CR-162547) ENVIRONMENTAL TESTING OF
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Environmental Testing of Block III Solar Cell Modules

Part I: Qualification Testing of Standard Production Modules

John S. Griffith

September 1, 1979

Prepared for
U.S. Department of Energy
Through an agreement with
National Aeronautics and Space Administration
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ABSTRACT

This report describes the results of qualification tests of Block III solar modules. Block III was the third large-scale procurement of silicon solar cell modules made by the JPL Low-cost Solar Array Project; the qualification modules were delivered in 1978. Block III modules continue to show improvements over Block I and Block II modules. Cell cracking and delamination are less prevalent, and interconnect problems and electrical degradation from environmental testing are now rare.

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SECTION I

INTRODUCTION

This report is in two parts. Part 1 describes the results of qualification tests on the principal components of the LSA Project Block III procurement of silicon solar cell modules. Part 2 will present the results of exploratory tests on these modules and of qualification tests of new designs developed later in the Block III procurement cycle.

Block III modules were procured by the Project for the test and applications projects of the Department of Defense (DOD), the Massachusetts Institute of Technology's Lincoln Laboratory (MIT/LL), and the NASA Lewis Research Center (LeRC). Three separate procurements of solar cell modules have been made for this purpose. The Block I procurement consisted of 58 kW of off-the-shelf-type modules, with deliveries mainly in 1976. Block II modules totalling 110 kW were constructed according to JPL specifications to meet uniform design and test requirements; deliveries were mainly in 1977. Block III is the current purchase of 227 kW of modules meeting Block II design and test requirements but with more uniform quality standards. Block III modules were delivered mainly in 1978. The next major DOE procurement of solar cell modules was accomplished through the DOE Albuquerque Operations Office under the Program Research and Applications Experiments (Reference 1). Block IV prototype modules, emphasizing the latest design and production technologies, are due for delivery to JPL late in 1979.

Environmental testing carried out on Block III modules was in three major categories: 1) initial production tests, 2) production sample tests, and 3) exploratory tests.

1. Initial Production Tests. A random sample of about 25 modules was selected from the first 200 modules produced. The sample modules were subjected to testing as follows:

- (a) Verification of contractor power measurement on all 25 modules
- (b) Measurement of thermal coefficients on ten modules only
- (c) Qualification testing of modules installed in a 1.2 m x 1.2 m (4 ft x 4 ft) subarray

2. Production Sample Tests. Random samples were taken at regular intervals from the completed modules at the vendors' plants. Qualification-type tests were performed on early samples mounted in two subarrays. Later samples were not environmentally tested except in special cases. Power measurements were made on all samples and a running average power verification was maintained.

3. Exploratory Tests. A quantity of modules equivalent to one subarray was set aside from the sample of 25. These modules are currently undergoing exploratory tests. The results will be presented later in Part 2 of this report.

Several characterization and performance tests were also carried out, including measurement of NOCT (Nominal Operating Cell Temperature), electrical isolation to ground, current-voltage characteristic (I-V curve), etc. The results of hail damage and voltage bias-humidity tests are reported in References 2 and 3.

SECTION II

MODULE DESCRIPTIONS AND SPECIFICATIONS

Block III modules were procured from five manufacturers, and were given manufacturer identification code letters R, U, V, Y, and Z. Figures 2-1 and 2-2 are front and rear photographic views of standard Block III modules, which are the subject of this report. A summary of their physical and electrical characteristics is given in Table 2-1. Table 2-2 contains identifying numbers and structural characteristics. Modules designated Y and Z are very similar to Block II Y and Z modules (Reference 4). Type V modules are similar to Block II VB modules, except that the substrate was changed.

Several variations of standard modules were included in the Block III procurement. These special Block III modules are described in the lower portion of Table 2-2. These modules resembled modules previously obtained in small quantities by LSA Project tasks.

Performance and test specifications are detailed in JPL Document 5-342-1C (Reference 5). Briefly, the requirements are:

- (1) Modules shall be designed to fit into a 1.2 m x 1.2 m (4 ft x 4 ft) subarray, with module group actual outside dimensions of 1.17 m x 1.17 m (46 in x 46 in).
- (2) A subarray shall supply at least 60 watts of power at 15.8 V, air mass 1 spectrum, 100 mW/cm² at 60°C cell temperature.
- (3) Electrical resistance to ground shall be 100 megohms or greater at 1000 Vdc and the module shall withstand a test voltage of 1500 Vdc at a leakage current of 50 micro-amperes or less.
- (4) Modules shall be capable of withstanding a twist of 1 part in 48 which might occur if a field mounting surface should be out of flat by that amount.
- (5) Environmental tests shall result in less than 5% electrical degradation. Mechanical degradation from test exposures must be acceptable per the Inspection System Plan. The following exposures shall be applied with the modules held in a rigid frame:

- (a) Temperature cycling

Fifty temperature cycles from ambient to +90°, to -40°C, and to ambient. Each cycle shall be completed in six hours or less, and rate of temperature change shall not exceed 100°/hr.

(b) Humidity

Two days of preconditioning followed by five temperature cycles from 23° to 40.5° C at 90% relative humidity.

(c) Cyclic pressure loading (also known as wind simulation or mechanical integrity test).

A uniform pressure load of +2400 Pa (50 lb/ft²) shall be applied alternately to the front and back surfaces of the modules for 100 cycles.

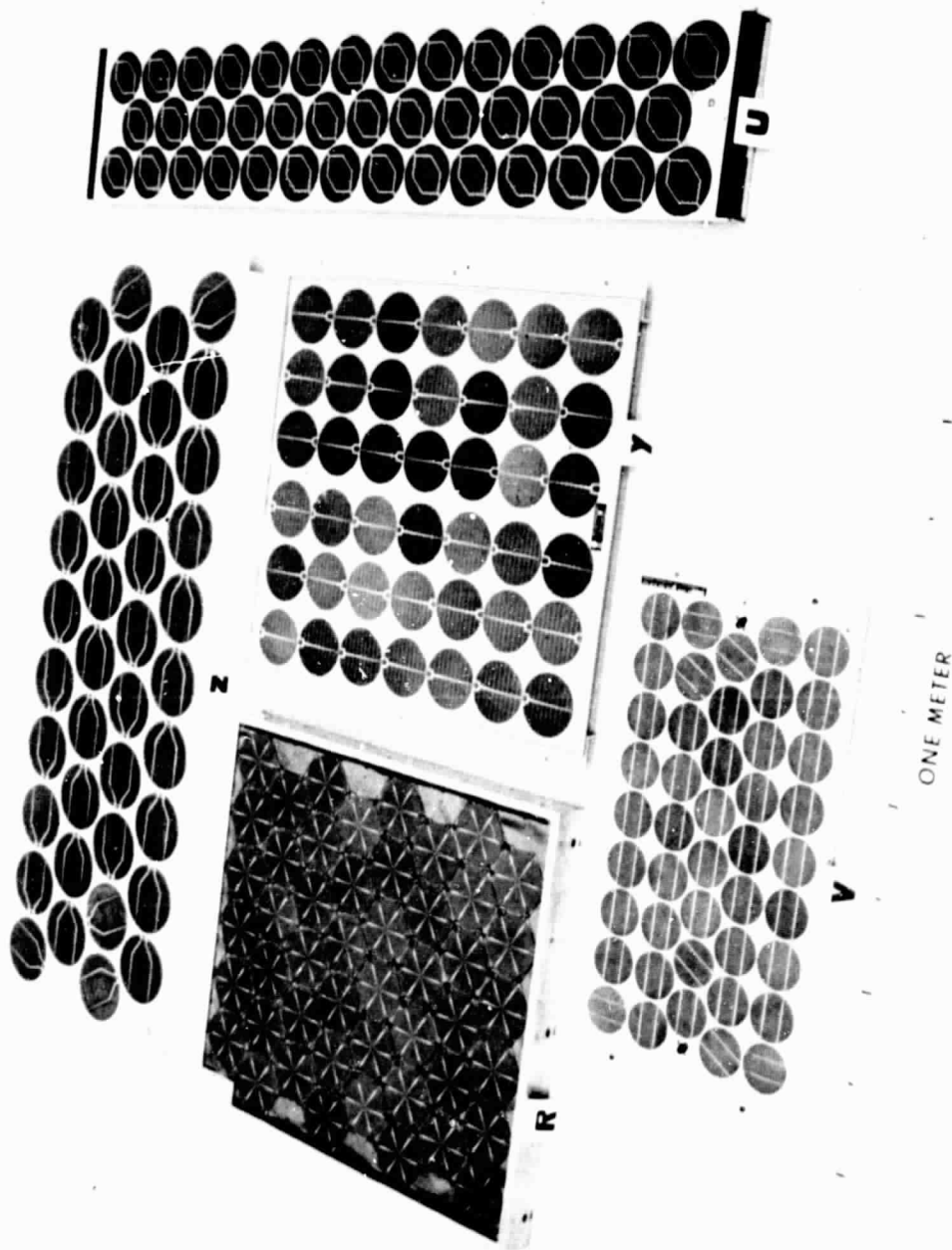


Figure 2-1. Block III Modules, Front View

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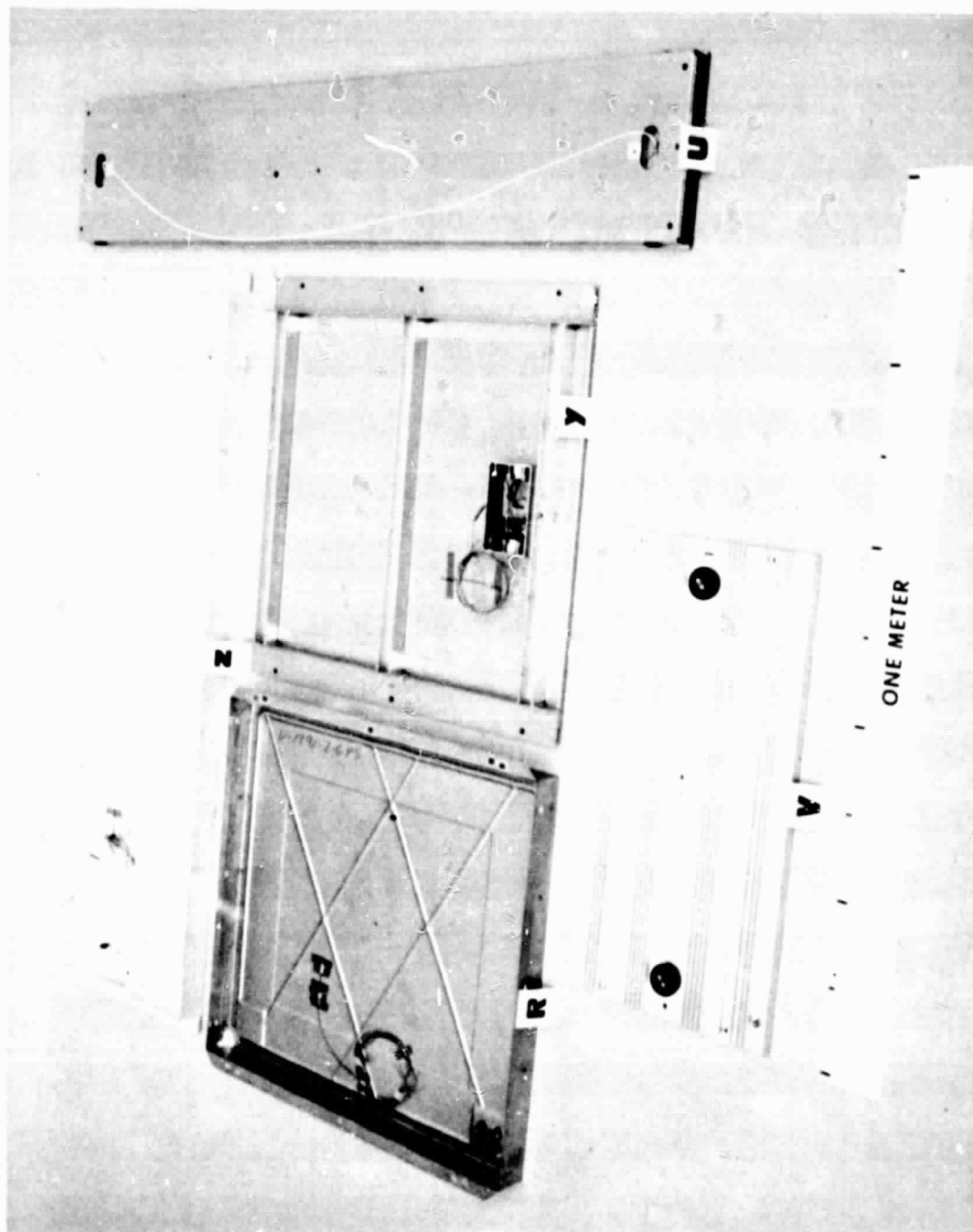


Figure 2-2. Block III Modules, Rear View

Table 2-1. Physical and Electrical Characteristics of Modules

Vendor Code						
Item	RR	RM	U	V	Y	Z
Maximum Power, 28°C, W	25.6	27.0	22.8	10.85	21.6	36.1
NOCT (Nominal Operating Cell Temp.), °C	61.0	61.0	57.2	-	47.1	46.0
RV (Rating Voltage), V	5.0	5.0	15.8	16.5	15.8	15.8
Power at 60°C and RV, W	21.9	23.7	18.95	9.11	17.7	30.7
Current at 60°C and RV, A	4.35	4.74	1.20	0.552	1.12	1.95
Nominal Cell Diameter, mm	76.2*	76.2*	76.2	54.8	76.2*	100.0
Nominal Cell Area, mm ²	4560.*	4560.*	4560.	2360.	4560.*	7854.
Module Length, cm	58.1	58.1	116.8	58.2	58.1	116.8
Module Width, cm	57.8	57.8	23.1	28.7	58.1	38.8
Total Cell Area, m ²	0.219*	0.219*	0.187	0.104	0.192*	0.314
Total Module Area, m ²	0.336	0.336	0.270	0.167	0.238	0.453
Packing Factor	0.65	0.65	0.69	0.62	0.57	0.69
Number of Cells	48.	48.	41.	44.	42.	40.
Average Weight, kg	6.56	6.51	3.66	3.70	4.52	7.36
Encapsulated Cell Efficiency, P _m , 28°C	0.116	0.123	0.122	0.104	0.113	0.115
Encapsulated Cell Efficiency, 60°C, RV	0.100	0.108	0.101	0.088	0.092	0.098
Module Efficiency, P _m , 28°C	0.076	0.080	0.084	0.065	0.064	0.080
Module Efficiency, 60°C, RV	0.065	0.071	0.070	0.055	0.052	0.068
Watts/kg, 60°C, RV	3.32	3.64	5.18	2.46	3.91	4.18
Temperature Coefficient, ΔV/ΔT, V/°C	-0.0256	-0.0243	-0.100	-0.1071	-0.1039	-0.0863
Temperature Coefficient, ΔI/ΔT, A/°C	0.00319	0.0023	0.000313	0.000075	0.000797	0.00046

NOTE: All power, current, and efficiency values at 100 mm/cm²; performance determined by measurement of as-submitted sample modules.

*Cell edges clipped; actual areas are less.

Table 2-2. Module Description and Structural Characteristics

Standard Block III Modules						
Item	Vendor Code	RR AND RM*	U	V	Y	Z
Model or Deg. No.		MSP11D10/MSP21D10.	ASI-18-1200.	20-10-1646.	A-0221.	E-10008F.
Top Cover		3.4 mm Solatex tempered glass.	3.2 mm Sunadex tempered glass.	None.	None.	Conformal coating DC XL-2577.
Encapsulant		Silicone dielectric gel.	Polyvinyl butyral.	Silicone RTV 615.	RTV 108 or Silastic clear.	Sylgard 184.
Backside Insulating Material		Copper foil interconnects on polyimide film, glass scrim cloth below.	White Teflon sheet 0.1 mm thick.	PVC coated fiberglass screen.	Random fiberglass-reinforced polyester 2.4 mm thick.	Fiberglass/polyester frame serves as insulator.
Electrical Feedthrough		Plated copper conductor in nylon insulator.	Brass terminal sealed with polysulfide.	Molded-in standoffs in a molded epoxy glass-filled block, stainless screws and protective neoprene boot.	2 slits in polyester for insulated wires to junction box.	Rivnut, steel, cad-plated. Junction box integral with frame.
Frame		Epoxy varnish coat on 0.46 mm stainless sheet inverted pan with bezel, poprivet construction (later spotwelded).	Glass laminate sealed in a 0.8 mm sheet aluminum frame with polysulfide. Ends of laminate are enclosed with black acrylic channels with polysulfide cement.	Extruded 6063-T6 aluminum-finned plate with aluminum end dams.	Formed 5052 aluminum frame, Allodyne or Iridite finish.	Random orientation fiberglass-reinforced molded white polyester.

*RM modules have cells made by a subcontractor.

Special Block III Modules		
VG2	- Same as V but glass-covered	YHD1 - Similar to Y but with high packing density, modified square cells
VG4	- Same as V but with 100 mm cells and a glass cover	YHD2 - Second version of high density modules

SECTION III

THERMAL CHARACTERISTICS OF MODULES

Two thermal characteristics were measured for each type of module: the Nominal Operating Cell Temperature and the temperature coefficients for voltage and current.

A. NOMINAL OPERATING CELL TEMPERATURE (NOCT)

NOCT is defined as the module cell temperature at 80 mW/cm², 20°C air temperature, 1 m/s wind speed, module surface normal to the sun's rays, open back and open circuited. The method is described in Appendix A of JPL Report 5101-76 (Reference 6). The NOCT values given in Table 2-1 are based on measurements of modules similar to standard Block III modules.

B. TEMPERATURE COEFFICIENTS FOR VOLTAGE AND CURRENT

Electrical output of photovoltaic modules decreases with increasing temperature. Typically, the power output of a module operating at a NOCT of about 45°C will be about 10% lower than under laboratory test conditions. The procurement specification for Block III modules (Reference 5) requires the rating of modules at 60°C and 15.8 V*.

Temperature coefficients were measured by putting ten modules of each type into a "hotbox," controlling the actual module temperatures to 28° or 60°C, and measuring and comparing the electrical characteristics at these two temperatures. Further details on these measurements are given in Reference 4 (pp. 3-1 to 3-3). Temperature coefficients as measured are given in Table 3-1. Since these measurements had not been made at the start of module production, estimated values were assigned for each module type. When the variance between the estimated and actual values was not too great, the estimated values were used throughout the production run. Although this report gives data using only the newly measured values, Table 3-1 shows both sets of coefficients with the value used by each manufacturer underlined.

*16.5 V for V modules, 5 V for R modules.

Table 3-1. Temperature Coefficients of Block III Modules*

	Rating Voltage	Voltage Coefficient V/°C		Current Coefficient mA/°C	
		Tentative	Measured	Tentative	Measured
RR	5.0	<u>.0285</u>	.0256	<u>2.46</u>	3.19
M	5.0	<u>.0285</u>	.0243	<u>2.46</u>	2.30
U	15.8	.110	<u>.100</u>	.384	<u>.313</u>
V	16.5	<u>.111</u>	.1071	<u>.43</u>	.075
Y	15.8	<u>.102</u>	.10391	<u>1.3</u>	.797
Z	15.8	.094	<u>.086</u>	0.45	<u>0.46</u>

*Coefficients used by vendor to determine power delivered are underlined.

SECTION IV

QUALIFICATION TESTING

Qualification testing as used in this report refers to those tests and packaging requirements described in the JPL procurement specification, Document 5-342-1C (Reference 5), Sections III A and II C. These tests were applied to the initial shipments of Block III modules as well as to production samples.

A. TEST PROCEDURES

Qualification test procedures are described briefly in Section II of this document, as well as in Reference 4, Section III.

B. EQUIPMENT AND FACILITIES

The equipment and facilities used to carry out the qualification tests are described in Reference 4, pp. 4-4 to 4-10. One of three environmental test chambers procured for this project (Figure 4-1) was temporarily installed at JPL in Building 144 for use starting in late July, 1979. The internal working dimensions of this chamber are 1.67 m x 1.67 m x 1.67 m (5.5 ft x 5.5 ft x 5.5 ft).

C. RESULTS

Qualification tests were carried out on one subarray of the initial set of modules and on approximately two additional subarrays of early production samples. The results, including principal types and extent of degradation observed, are shown in Table 4-1 and are discussed below. Temperature coefficients were measured on ten modules of each type in a temperature-controlled box. These results are given in Table 3-1. The Nominal Average Power was measured for approximately 25 modules of each type randomly chosen from the first 200 produced. This provided verification of manufacturers' power measurements. A running average of power measurements was maintained using the average power of the first 25 modules, properly weighted, and that of all production samples subsequently delivered. The final averages are presented in Table 2-1.

D. DISCUSSION

Cell cracking was observed on three of the five types of modules. It was found rarely on R and U modules and in only a few cases on Z modules. Cell cracking in Z modules was attributed to air trapped under the cells. No significant electrical degradation was found in any of these modules, however any cell cracking is considered potentially serious.

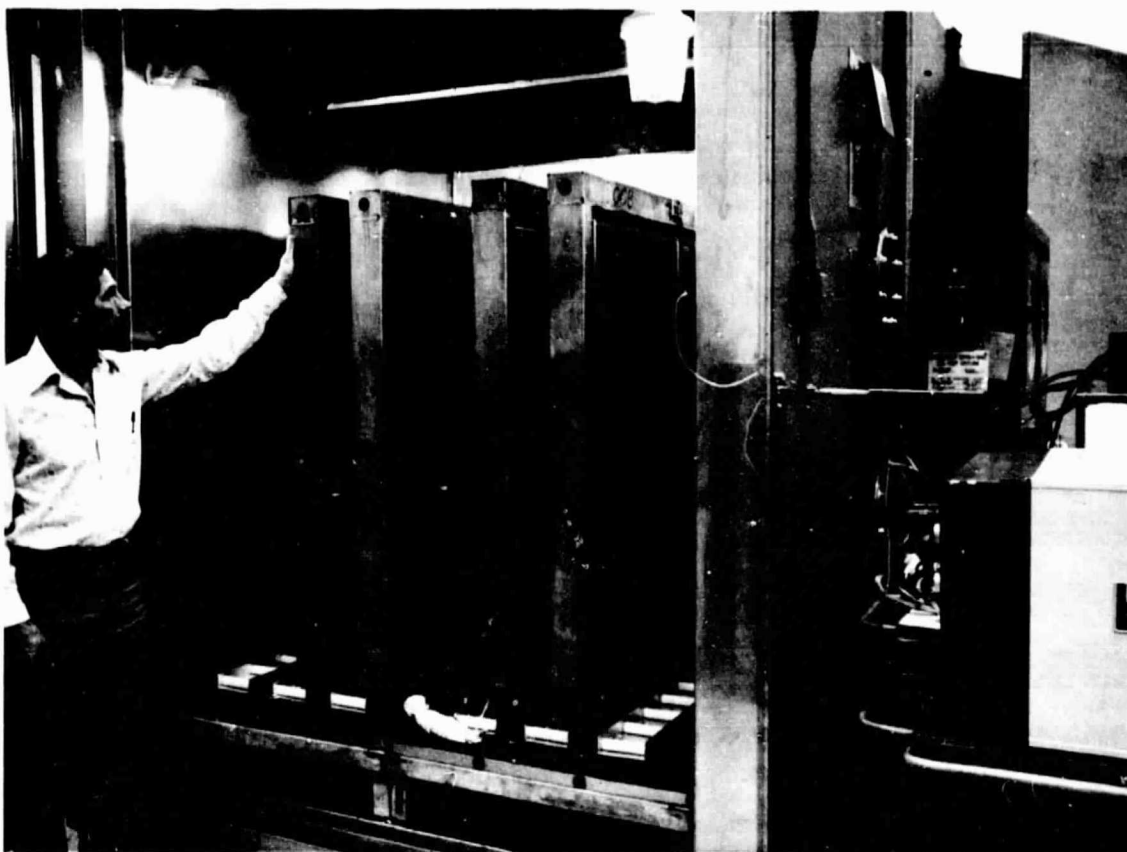


Figure 4-1. Environmental Test Chamber

Encapsulant problems occurred in three of the five types of modules. Bubbles were very prevalent in early R modules but did not appear at the time the last subarray (four modules) was tested; the encapsulant fill process had been improved. Delamination in Z modules occurred at the interconnects and near the frame at the edge of the encapsulant. This persisted throughout testing but diminished somewhat after changeover to use of a different primer.

The soldering problem with the V module was a single case of no solder on either of the two back contacts on one cell. The module developed an open circuit during testing.

Noted under "Other" in Table 4-1 were the lifting and shrinkage of acrylic end channels on U modules. These channels were incorporated to assure the safety of field operating personnel against high voltage. Although the processing was improved, the problem continued until the end of testing. Terminal corrosion of V modules occurred on the first set tested and did not recur. Cell discoloration observed on the second subarray of Y modules tested did not recur on the third and final subarray.

Table 4-1. Results of Qualification Tests of Block III Modules

Supplier	Number of Modules Tested	Cell Cracks	Encapsulant			Workmanship, Soldering	Other
			Bubbles	Delam	Leaks		
R	16	●	● ¹		● ¹		
U	20	○					● ²
V	23					●	○ ^{1,3}
Y	12			●			● ^{1,4}
Z	11	○○		●○			

● Temperature Cycling

○ Humidity Cycling

⊙ Wind Simulation

} Circle size reflects frequency and severity of degradation

1. Problem not found in latest modules.
2. Lifting and shrinkage of acrylic end channels.
3. Corrosion of terminals.
4. Cell discoloration.

E. CONCLUSIONS

Block III modules showed improved performance over Block II modules in environmental qualification tests; in no category was their performance inferior to that of Block II modules. Earlier results showed that Block II modules performed considerably better than did Block I modules.

No significant electrical degradation such as was commonly found in previous procurements was observed in any of the 82 Block III modules tested. (The unsoldered V interconnects are not considered electrical degradation in the usual sense.) By the conclusion of the testing, significant delamination was present only in modules of one supplier.

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*JPL internal document.